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Nonlinearity and chaos in wireless network traffic

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ABSTRACT

The natural complexity of wireless mobile network traffic dynamics has been assessed in this article by tracing the presence of nonlinearity and chaos in the profile of daily peak hour call arrival and daily call drop of a sub-urban local mobile switching centre. The tools like Recurrence Plot and Recurrence Quantification Analysis (RQA) has been used to reveal the probable presence of non-stationarity, nonlinearity and chaosity in the network traffic. Information Entropy (IE) and 0–1 test have been employed to provide the quantitative support to the findings. Both the daily peak hour call arrival profile and the daily call drop profile exhibit non-stationarity, determinism and nonlinearity with the former one being more regular while the later one is chaotic.

1. Introduction

In view of continuous high demand for low cost multiple services through wireless networks, the service providers are under tremendous pressure for technological and infrastructural up gradation of network systems with sufficient quality of service (QoS). Maintaining the dropped call rate and traffic congestion within permissible limits are among the most important QoS parameters responsible for customer satisfaction and hence for the revenue generation. Providing multi-class services through next generation wireless networks with desired QoS has brought in multiple challenges like admission control, congestion control and system design. Report of the Telephone Regulatory Authority of India (TRAI) [28] indicates a steep increase on the demand of network services through wireless technology since its inception with the dropped call rate to be more than maximum permitted 2% (in fact, it is around alarming 3% or more). To improve the quality of service and to achieve the optimum performance there is an utter need to understand the dynamics of the wireless network traffic which in turn will facilitate to have its desired effective model.

Many researchers are already paying their efforts to design efficient model of wireless network traffic applying statistical methods. Some of major works are like Wireless network traffic prediction using neural network as well as statistical methods [10,11], stochastic modelling for evaluating the channel availability and predicting the call arrival rate and call holding time [13], security of the transmitted data in a wireless network using chaotic encryption method [14], forecasting chaotic time series generated from wireless communications using Echo State Networks (ESNs) [12]. Though these works are focused on the modelling, forecasting and security of the system neglecting the intricate dynamics (in particular the nonlinearity) of the systems, their works may slither in real application.

Some researchers are putting their efforts on this aspect of the network traffic. The chaotic nature of the TCP protocol, used in 3 G UMTS mobile networks has been studied by Vasalos et.al [29]. The routing algorithms in a real communication networks have been evaluated to explore the presence of chaos in operational conditions [18]. Different models like ARIMA, FARIMA, wavelet based and neural network based model are used for traffic prediction of WLAN [4]. The detail of nonlinearity of QoS and Quality of User Experience factors in a wireless & mobile network are discussed by Herman et.al (Herman, Rahman, Syahbana, & Bakar). A network-based anomaly detection and recurrence plot-based traffic classification approach based on the analysis of non-stationary "hidden"

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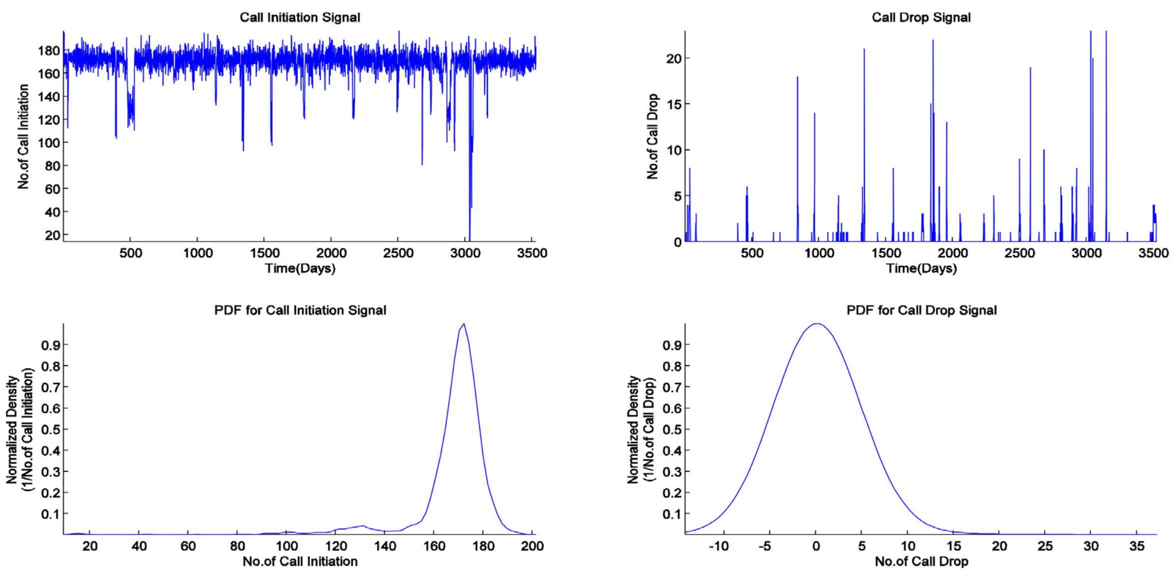

Fig. 1. Plot of the daily busy hour call initiation and dropped call signals and their normalized pdf plots.

transition patterns of IP traffic flows can be found in some works [24,23].

The dynamics of network traffic is highly influenced by the parameters like busy/peak hour call arrival rate and call drop rate. Understanding the nature of fluctuations of these two parameters is of paramount interest to estimate the dynamics, in particular complexity, of wireless network traffic. Nonlinearity and chaos are the indices to assess the degree of complexity of a particular dynamics. This paper intends to discover the existence of nonlinearity and chaos along with their characteristics within the dynamics of the daily busy/peak hour call arrivals and daily dropped calls time series of a sub-urban local mobile switching centre during 3rd March 2004 to 31st October 2013. Recurrence Plot (RP) & Recurrence Quantification Analysis (RQA) have been used to confirm the existence of chaos in these two time series and also to estimate its character (stochastic or deterministic). Information Entropy (IE) has been employed to measure the amount of average information that can be obtained from these two time series signals (Dropped call and Call initiation) in order to confirm their regularity/chaosity. 0–1 Test has been used for detection of chaosity in order to authenticate the outcomes resulted from the RP, RQA and IE.

2. Experimental data

Primarily the real time data are logged in the Data Log Server placed in the MSC (Mobile Switching Centre) of the ISP. The logged data sets are collected from the Data Logger of the ISP located in our city for the period 3rd March 2004 to 31st October 2013 exclusively for research purpose. The data is strictly not allowed for any commercial purpose. The collected data include information of call initiation, call holding time, call drops and its causes, time and delay of hand-off etc. From this data we have considered the call initiation and the call drop statistics for each hour of a day. Finally the peak/busy hour call initiation and the call drop statistics have been considered as the consolidated signals for analysis. Fig. 1 shows the plots of both the data sets and their corresponding normalized probability density function (pdf) plots. The summary statistics of the experimental data sets are tabulated in Table 1. Fig. 1 and Table 1 basically provide the statistical introduction of the signals under investigation in this paper to the readers.

Fig. 1 show that the pdf of the call drop signal is normally distributed with a single peak or local maxima whereas the pdf of the call initiation signal is normally distributed with two unequal peaks or local maxima. Such kind of distribution in case of call initiation signal with two different modes is known as bimodal distribution of pdf [5]. In time series the larger mode is known as the major mode or acrophase, the fewer mode is known as minor mode and the least frequent value between the two modes is known as the antimode or batiphase. Most commonly bimodal distribution arises from the mixture of two unimodal distributions. Such kind of distribution frequently occurs in natural phenomena such as colour of galaxies, age distribution and growth estimates of the fish population, sediments, daily water distribution and also in traffic analysis, where traffic peaks in during the AM rush hour and then again in the PM rush hour.

Table 1
Summary statistics for daily dropped call and busy hour call initiation signal.

Scores	Call Initiation signal	Call drop signal
Mean	168.3904	0.2575
Median	171	0
Mode	171	0
Standard deviation	14.7791	1.3501
Variance	218.4217	1.8229
Maximum	197	23
Minimum	14	0
Degrees of freedom	2.8337e-04	2.8337e-04
Skewness	−3.9661	10.0751
Kurtosis	29.4186	134.2273

3. Recurrence plot (RP) & recurrence quantification analysis (RQA)

3.1. Recurrence plot

It is a pictorial representation (or a graph) [20,2] of a square matrix, in which the matrix elements correspond to those times at which a state of a dynamical system recurs [2,19]. This method provides a way to think about the periodic nature of a trajectory through a phase space, which is formed by the delayed vectors of dimension d. This state trajectory within the d-dimensional phase space is represented on a 2-D squared matrix with black and white dots representing ones and zeros. Both axes are time axes. Between two different time instances i and j, the change of state of the